

# Electrically Induced Redox Barriers

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## **e<sup>-</sup> barrier Concept**

The concept of an electrically induced redox barrier (e<sup>-</sup> barrier) is that of a permeable reactive barrier driven by low voltage D.C. current. This is accomplished by installing closely spaced (planar) permeable electrodes transverse to flow through a targeted plume. Sequential oxidizing and reducing conditions are generated about the positive and negative electrodes, respectively.

A series of laboratory experiments conducted over the past 3 years have suggested that potential advantages of an electrolytic approach are:

- 1) *in situ* redox conditions can be modified without the introduction of chemicals,
- 2) sequential oxidation and reduction can be imposed via a single process, and
- 3) cost may be favorable for a significant set of conditions.

Promising results from laboratory studies have suggested that a field-scale evaluation of an e<sup>-</sup> barrier was needed. The following describes highlight of our e-barrier research.

## **CFB Borden Prototype**

Building on column and tank studies, a prototype e<sup>-</sup> barrier (6 by 8 feet) was designed and constructed in the summer of 2001. The barrier consists of a set of three titanium mesh electrodes fabricated into a panel. HDPE geonet spacers separate the electrodes. The exterior of the panel is covered with a geotextile that limits sand invasion. The panel is framed in three inch PVC pipe. The PVC frame provides structure, conducts electrical connections to grade, provides a washout for precipitates and acts as a header for gas collection. The panel is connected to a D.C. rectifier. Performance is monitored 1) using a data logger that tracks voltage, amperage, and reference electrode voltages up and downstream of the panel and 2) through sampling of 118 multi-level sample points up and downstream of the barrier.

The barrier was installed downgradient of a PCE/TCE source at Canadian Force Base, Borden, Ontario, in the fall of 2001. In January of 2002, after a three-month equilibration period, power (5V) was applied to the barrier. Analysis of performance is ongoing.

Data collected through the first phase (165 days) of operations indicate steady current densities of 1.76 amp/m<sup>2</sup> at 5.32V. Stable amperage suggests the electrodes are not degrading and that scale control measures are effective. Power consumption is 9.4 watts/m<sup>2</sup> (~\$US 0.01/day-m<sup>2</sup>). Up and downstream reference electrode values of +1.5 and -1.4 (SHE) suggests the potential to drive mineralization of PCE and TCE via both oxidative and reductive pathways. Observed removal of PCE is in excess of 99%. A complicating factor is that part of the observed removal is likely due to adsorption of PCE in the panel. Analysis of TCE removal is complicated by production of TCE from PCE degradation. Decreases in TCE downgradient of the panel after start up suggest that substantial TCE is also being removed. Minor amounts of cis-DCE have been observed downgradient of the barrier. No VC has been detected. Subsequent operations have evaluated barrier performance at 7.8 V (80 days) and 10.9 V (45 days). Data analysis is ongoing.

## **Energetic Compounds**

Building chlorinated solvent studies, SERDP funded a proof-of-concept study to assess the efficacy of e<sup>-</sup> barriers for remediation of energetic compounds in groundwater. Six identical flow-through electrolytic column reactors were packed with quartz feldspar sand to test treatment efficacy for TNT and RDX. Expanded titanium-mixed metal oxide electrodes spaced 2 cm apart were placed at the midpoint of the columns. The columns are one-dimensional analogs for groundwater flow through an e<sup>-</sup> barrier. For each contaminant, one column was a no

voltage control, one was an oxidation-reduction sequence, and one was a reduction-oxidation sequence. Studies were conducted using influent concentrations of 1,000 ug/L TNT and 500 ug/L RDX. Aqueous concentrations of TNT, RDX and reaction intermediates were determined using HPLC-UV and GC/MS.

Analyses conducted using GC/MS indicate removal of greater than 97% and 93% of the TNT and RDX, respectively, relative to the control, using the oxidation-reduction sequence. These values reflect measured effluent concentrations less than detectable levels. Replicate analyses using HPLC-UV indicated greater than 97% for TNT and 98% for RDX relative to the control reactors. Removal may be greater due to analytical constraints. Known degradation intermediates were not observed using sequential oxidation-reduction. Removal rates for TNT and RDX were lower in reactors testing sequential reduction-oxidation. In addition, the reduction-oxidation sequence produced detectable reaction intermediates. Based on the results of this study, current plans are to conduct additional laboratory studies focused on resolution of reaction pathways, kinetics, and site-specific treatability studies.

### **F.E. Warren AFB Demonstration**

In 2000, ESTCP funded a field demonstration project to evaluate cost and efficacy associated with field application of e<sup>-</sup>barrier technology. The site selected for the demonstration was F.E. Warren Air Force Base. F.E. Warren AFB is located in southeastern Wyoming, immediately west of Cheyenne. F.E. Warren is an approximately 7,000-acre facility with surficial eolian and fluvial deposits. The alluvium is underlain by the Ogallala Formation. Locally the Ogallala Formation consists interbeds of gravel, sand, and silt with varying clay content. Through historical maintenance and disposal activities, chlorinated solvents (primarily TCE) have inadvertently been released to the subsurface.

Building on the results of the column and tank studies, a field barrier designed and fabricated. It consists of 17 separate panel connected by PVC interlocks. The height and length of the barrier is 1.8 by 9.2 meters, respectively. The barrier was installed at F.E. Warren AFB on August 26-28, 2002. A trench box was set to the target depth. The reactive barrier was placed in the excavation with a clean sand backfill to the watertable. The remainder of the excavation was backfilled with clean site soil. A network of 144 sampling points has been established. This will be used to characterize shifts in pH, Eh, inorganic water quality, and concentrations of target compounds (TCE and degradation products). Through the fall of 2002, baseline water quality data has been collected. The barrier was activated on January 27, 2003. The panel will be operated for approximately one year. Documentation of results including construction and performance will occur in 2004.